Asteroid spin and shape inversion for simulated Gaia photometry

Dagmara Oszkiewicz[1], Karri Muinonen[1,2] and Tuomo Pieniluoma[1]

[1] Department of Physics, P.O. box 64, FI-00014 University of Helsinki, Finland.
[2] Finnish Geodetic Institute, P.O. box 15, FI-02431 Masala, Finland.

Introduction

While determining and cataloging astrometric positions and movements of about one billion stars, Gaia will observe some hundreds of thousands of asteroids [1]. Photometric data of asteroids will consist of single brightness values ranging over a time interval of five years. This results in a maximum of about one hundred brightness values at varying observing geometries. Here we apply Markov-chain Monte-Carlo methods [2] to simulated asteroid data in order to obtain spins and shapes of the simulated asteroids (for conventional convex inverse methods, see [3] and [4]). The inverted and original shape and spin solutions are compared to validate the applicability of the methods to the Gaia data.

MCMC sampling

We make use of general convex shapes described using a large but finite number of triangles with or without smoothing using bicubic splines. In MCMC convex inversion, the convex shape solutions are directly sampled. There are four parameters for the spin characteristics: the rotational period, the ecliptic longitude and latitude of the rotational pole, and the rotational phase of the object at a given time. The $3N$ Cartesian coordinates of the N triangle nodes constitute the free shape parameters. Altogether, there are $3+3N$ free parameters [2]. In MCMC convex inversion, the inversion parameters are sampled according to the Metropolis-Hastings algorithm [5]. The accepted shapes and spins generate a sequence, a Markov chain. The proposed spin and shape parameters are accepted or rejected depending on the a posteriori probability density values corresponding to the proposed and current parameters. If the proposed parameters provide a better fit to the data than the current, they are always accepted. If the fit is worse, the candidate is accepted with a certain probability.

Simulated Gaia photometry

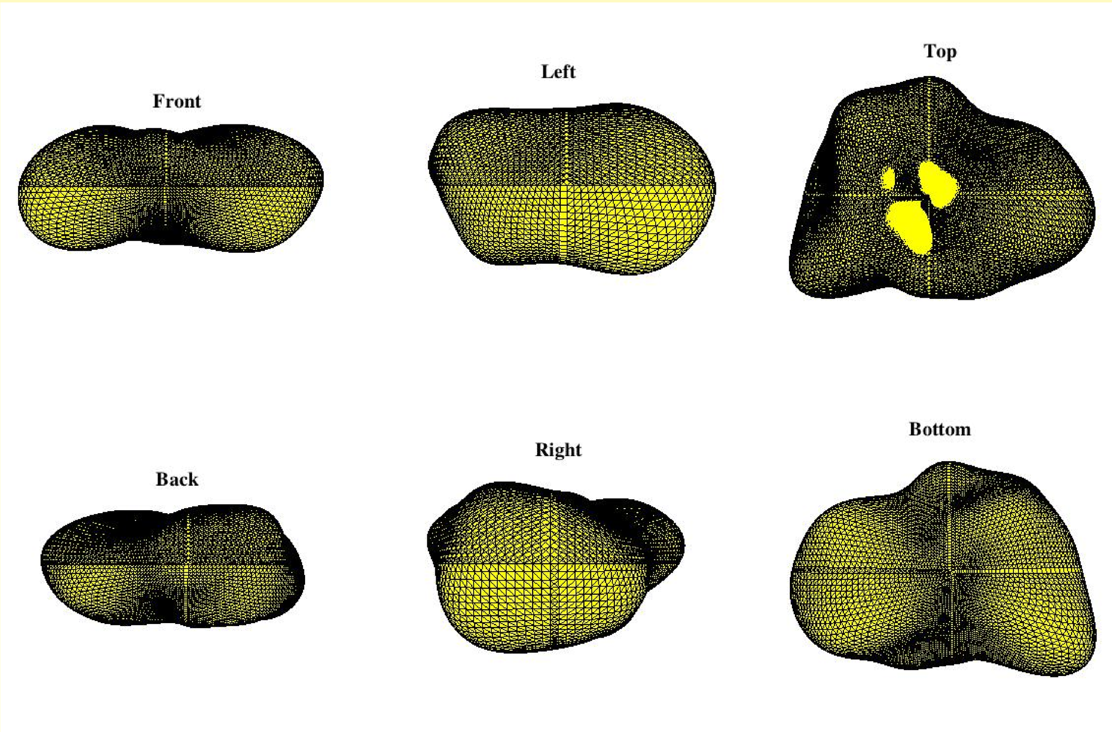
The data was generated for a Gaussian sample sphere mimicking an asteroid. The observing geometries were those simulated for asteroid Vesta for the five-year mission duration [6]. The data for Vesta amounts to 69 brightness values. The accuracy of the simulated data was 0.01 mag.

(21) Lutetia data

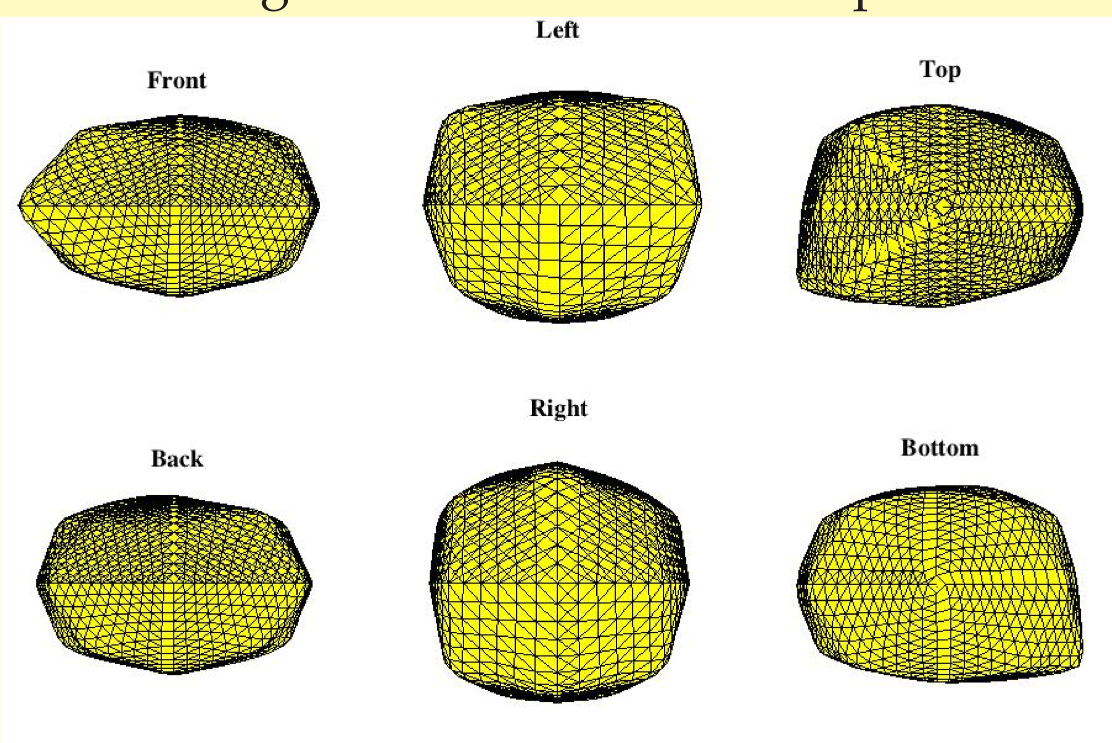
We have also applied the method to (21) Lutetia which is an M-type, main-belt asteroid (about 100 km in diameter). (21) Lutetia will be the object of a flyby (10 July 2010) by the Rosetta space probe on its way to the comet 67P/Churyumov-Gerasimenko.

Here we make use of the 26 lightcurves, making the total of 1326 photometric observations over a period of 35 years 3 months and 26.56 days from the Standard Asteroid Photometric Catalogue (SAPC) - http://asteroid.astro.helsinki.fi/.

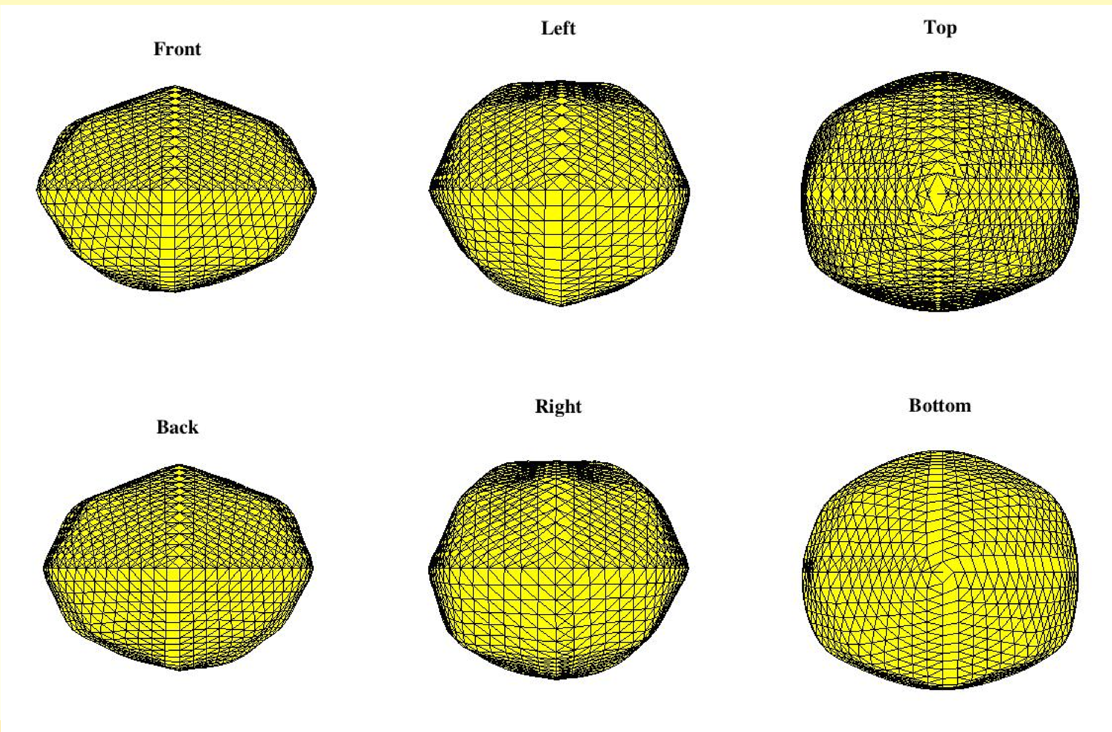
Shape



Above: Original shape used to simulate Gaia data. Below: Shape inverted from the simulated photometric Gaia data using convex stochastic optimization. The best fit resulted in an rms-value of 0.02. In inversion, three triangle rows were utilized per octant.

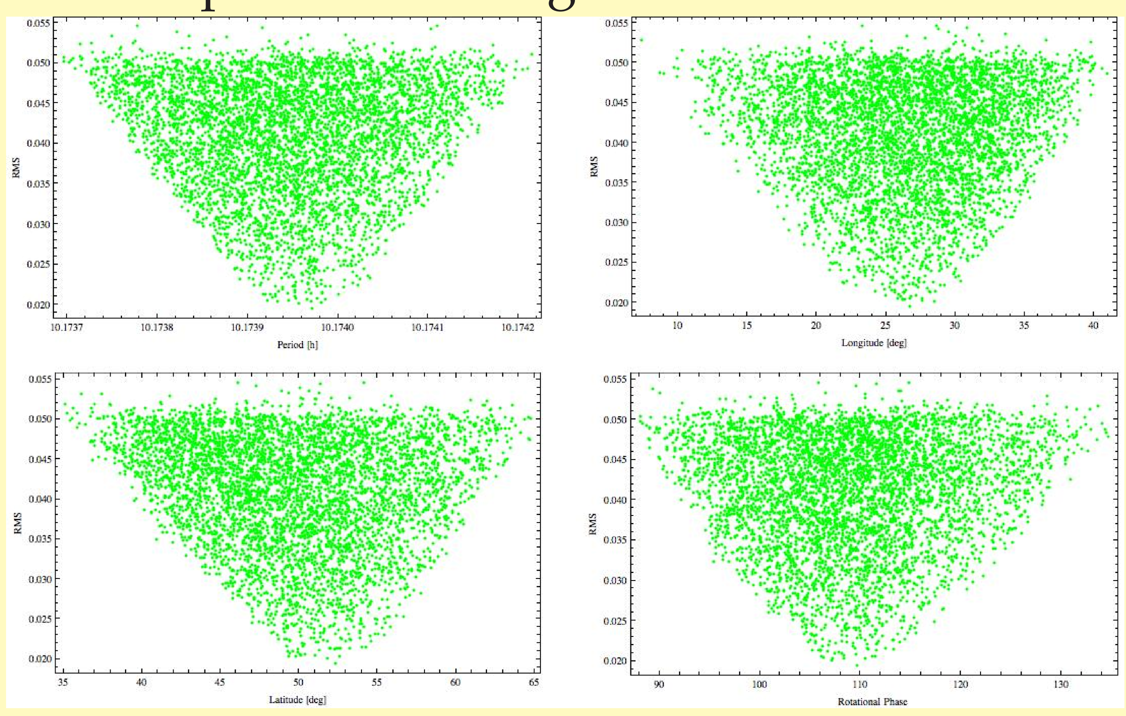


Overall the shapes are in agreement, but the locals valleys and hills are hidden. Below: Shape inverted from the photometric lightcurves of asteroid (21) Lutetia using convex stochastic optimization.

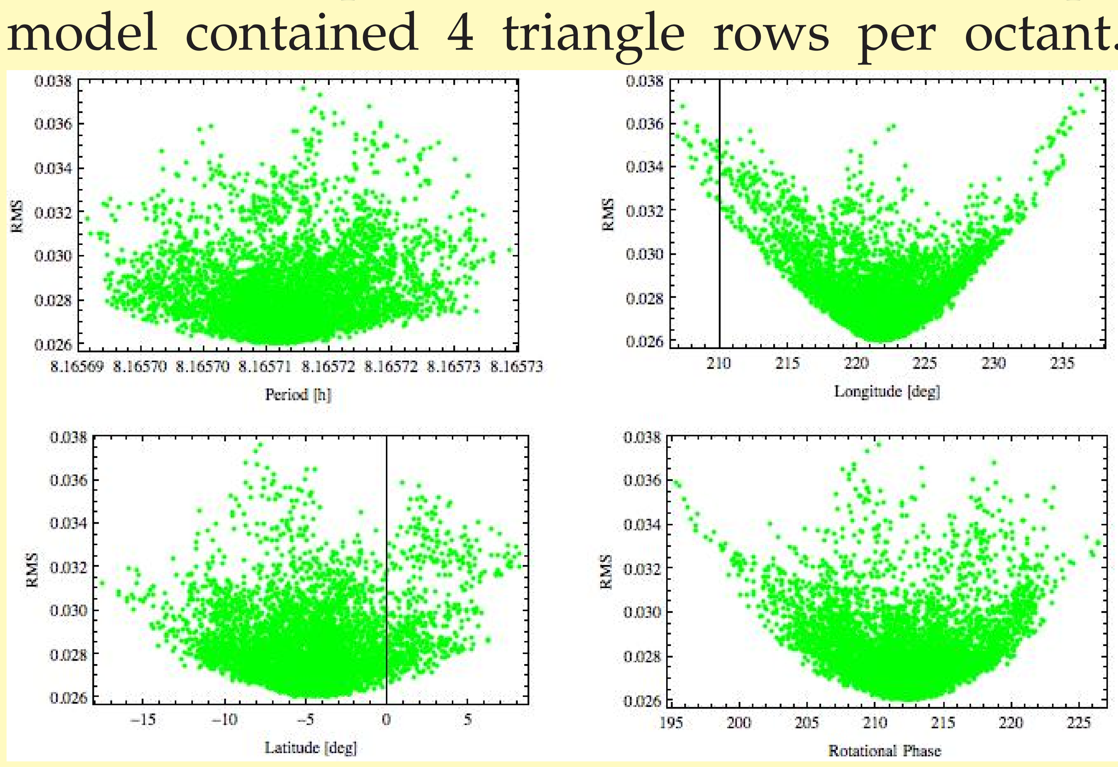


Rotational period and pole

Below: Rotational period and pole distributions as obtained from MCMC convex inversion for the simulated Gaia data. Original spin parameters: rotation period 10.17395622 h, ecliptic longitude of rotational pole 25.02 deg, ecliptic latitude of rotational pole 62.89 deg, rotational phase 110.1 deg.



Below: Rotational period and pole distributions around one of the possible poles obtained from MCMC convex inversion for asteroid (21) Lutetia. Here we used 100 chains and 50 samples in each chain. We utilize a two-dimensional proposal p.d.f. for the spherical pole coordinates with mean 1.0 deg and standard deviation of 0.1 deg. The proposal standard deviation for the period is 10^{-6} h. The shape model contained 4 triangle rows per octant.



Torppa et al. [3] list two pole solutions for (21) Lutetia: β_1 = +3 deg, λ_1 = 39 deg, β_2 = +3 deg, λ_2 = 220 deg, a rotational period of: P = 8.165455 hrs, obtaining the best fit rms 0.02. This is in accordance with our estimate.

Conclusions

We have applied convex stochastic optimization and MCMC inversion methods to derive asteroid spins and shapes using simulated Gaia photometry. The original and inverted shapes are overall in good agreement. The local features are not reflected in the inverted shape. MCMC asteroid lightcurve inversion methods can potentially be applied to the forecoming asteroid photometric observations by the Gaia mission [6] or the lightcurves stored in Standard Asteroid Photometric Catalogue (http://asteroid.astro.helsinki.fi/).

References

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